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Industrial Heat Pump Market Study

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Prepared For
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The following report was funded by the Bonneville Power Administration (BPA) to assess emerging technology topics that have the potential to increase energy efficiency. BPA is committed to identify, assess, and develop emerging technologies with significant potential for contributing to efficient use of electric power resources in the Northwest.

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1 Executive Summary

1.1 Introduction

Industrial heat pumps (IHPs) are a promising technology that will play a significant role in industrial decarbonization. They work by using electricity to move heat from one location to another, a method that is more efficient than direct heating using electricity or a thermal fuel source. Favorable conditions for heat pumps exist in industrial facilities with low-medium temperature process heating needs than can be matched with available waste heat streams.

Cascade Energy, Inc. performed a study to explore the potential for IHPs across diverse industrial segments within the service territory of the Bonneville Power Administration (BPA). The study involved scoping assessments at two locations in five distinct industry segments. The primary objective was to determine which sectors are most viable for implementing IHPs.

To do this it's crucial to understand the unique challenges and opportunities presented by each industrial segment. These insights not only frame the context for selecting appropriate heat pump technologies but also illuminate the strategic considerations that can guide decision-making. By examining the distinct characteristics, energy demands, and existing heating solutions of each segment, the rationale behind the tailored heat pump recommendations that follow can be appreciated.

Insights and Considerations:

- **Varied Energy Demands:** Different segments have diverse requirements for heat in terms of both scale and temperature, affecting the suitability of heat pump types.
- **Existing Infrastructure:** The current heating solutions in place, whether they rely on electric resistance, natural gas, or biomass, significantly influence the feasibility and economic attractiveness of transitioning to heat pump technologies.
- **Economic and Environmental Goals:** Each segment's operational priorities, whether driven by cost reduction, energy efficiency improvements, or greenhouse gas (GHG) emission reductions, play a critical role in the selection process.

Challenges:

- **Technical Feasibility:** There are technical constraints associated with retrofitting existing facilities with new heat pump systems, especially in segments with large and complex heating needs.
- **Economic Hurdles:** The upfront costs and return-on-investment associated with different heat pump technologies can vary widely, impacting the willingness to invest.

- **Regulatory and Policy Considerations:** External factors such as incentives, subsidies, and regulatory requirements can also influence the decision-making process.

Opportunities:

- **Energy Savings and Efficiency Gains:** Across all segments, heat pumps offer the potential for significant energy savings relative to less efficient full-electric options. Adopted at scale, they will play a critical role in mitigating load growth as industries electrify.

- **GHG Emission Reductions:** For segments particularly focused on sustainability and reducing carbon footprints, heat pumps represent a valuable strategy to achieve these objectives.

- **Innovation and Leadership:** Adopting advanced heat pump solutions can position companies as leaders in energy innovation, contributing to a competitive advantage and aligning with broader industry trends toward sustainability.

Industrial Segments:

1. Pulp and Paper
2. Chemical
3. Food Processing
4. Wood Products
5. High Tech

The selection of industrial segments for the study was based on their substantial presence in the Pacific Northwest. This "substantial presence" was defined by two key factors: the total electrical load and the total number of operational facilities within each sector. Prior to this study, only food processing sites had been evaluated by BPA for their potential to utilize IHPs. Therefore, a deeper exploration into the others was needed. Moreover, the study was designed to provide participating facilities with valuable insight into the viability of IHPs at their facility.

1.2 Summary Of Findings & Recommendations

The study confirms the economic feasibility of heat pump technologies across all five industry segments analyzed, with specific insights and recommendations as follows:
Economic Viability and Alternatives:

- **General Viability:** Heat pump opportunities show economic viability across all five industry segments. Air-source heat pumps emerge as a simpler and more cost-effective alternative for many applications, potentially substituting more complex and expensive heat pump systems.

- **Air-Source Heat Pumps for DHW:** For two sites without viable IHP applications, commercial-style, air-source heat pump water heaters (HPWHs) present marginal opportunities for domestic hot water (DHW) heating.

Equipment Replacement Considerations:

- **Replacing Electric Resistance Heaters:** Given the efficiency gains, facilities using electric resistance heat should strongly consider upgrading to heat pumps. Even a partial integration to remove load from the electric resistance system should be considered.

- **Thermal Fuel Equipment:** When replacing equipment that uses thermal fuel, the "spark gap" (the cost ratio of electricity to fuel) becomes a critical factor in evaluating the project's feasibility.

Industry-Specific Insights:

- **Chemical and High Tech:** These segments exhibited a higher potential for successful IHP projects, particularly due to their significant, consistent need for low-temperature process water heating and the presence of electric resistance heating equipment.

- **Pulp, Paper, and Wood Products:** The utilization of biomass boilers in these segments hinders favorable IHP project outcomes. The low cost of hog or wood scrap fuel leads to long payback periods or negative cost savings for IHP projects, alongside minimal or negative GHG reductions due to the carbon-neutral nature of biomass.

Further Recommendations:

- **In-Depth Study:** Additional research is needed in each industry segment to conduct a thorough savings analysis and obtain detailed vendor pricing.

- **Utility Program Baselines:** The consistent application of all-electric current practice baselines should be explored, to provide DSM programs a consistent framework to support the adoption of IHPs.

- **Regional Heat Pump Potential:** A broader evaluation of the overall potential for heat pump technologies in the Pacific Northwest is necessary, focusing on their impact on energy savings and electrical load.

These findings and recommendations aim to guide stakeholders in making informed decisions about adopting heat pump technologies, highlighting the need for further investigation and consideration of industry-specific and regional factors.

2 Overview Of Scoping Assessment Process

Participants for the study were selected from companies that are active participants in BPA's Energy Smart Industrial (ESI) program and have successfully implemented multiple energy efficiency projects. All but one company is also enrolled in ESI's Strategic Energy Management

(SEM) or Energy Program Manager (EPM) program offerings. SEM and EPM provide a more comprehensive approach to energy management that creates high-level commitment and promotes long-term goals. These organizations are likely to recognize the connection between energy efficiency and GHG reduction and be among the early adopters of IHPs and electrification technologies.

The following general process was followed in each on-site scoping assessment to identify and quantify heat pump measures:

1. **Identify Primary Heat Sinks:** Determine where heat is used on-site, including the temperature and heat requirements for each usage point.

2. **Identify Primary Heat Sources:** Locate sources of waste heat on-site that could potentially be upgraded by a heat pump to high quality process heat. Determine the temperature and heat available for each heat source.

3. **Determine Potential Heat Pump Measures:** Match heat sinks and sources, considering factors such as:
   a. Temperature of sink/source (only sink temperatures below ~225 °F were considered since most current market-ready heat pumps operate below this point).
   b. Magnitude and timing of heat required vs. magnitude and timing of heat available
   c. Practicality of integrating heat sources to sinks.
   d. Alternative, more cost-efficient methods for heat utilization, such as direct heat recovery.

4. **Calculate Heat Pump Lift:** Estimate the temperature difference between the sink and source (lift) which affects the heat pump’s efficiency. Use this lift to calculate the Coefficient of Performance (COP), with the understanding that a higher lift requires the heat pump to expend more energy to transfer heat.

5. **Calculate Heat Pump Energy Impact:** Based on the heat required, heat available, and the COP, calculate the electricity consumption of the heat pump. Calculate electric spend using the current utility rate and calculate cost savings compared to existing fuel spend. Calculate simple payback using estimated heat pump cost.

6. **Calculate Heat Pump GHG Impact:** Calculate the GHG emissions impact of implementing the heat pump solution.

For the steps laid out above, the following significant assumptions were considered:

- **COP:** The COP was calculated from lift using a curve fit equation derived from actual heat pump performance data. See ***Figure 5*** in the Appendix.

- **Heat Calculations:** The required and available heat quantified in these studies was based on equipment nameplate information, high-level control system reviews, discussions with facility staff regarding operations, and engineering assumptions and calculations. Half of the studies included a more thorough review of control system data to determine operating conditions and setpoints.

- **Capital Costs:** IHP equipment and installation costs were estimated using average heat pump cost information published by the American Council for an Energy-Efficient Economy (ACEEE). See ***Table 4*** in the Appendix.

3 Scoping Results

3.1 Heat Pump Characteristics

In the study, 25 heat pump projects were identified across the five industrial segments, with each of the ten evaluated sites represented in the findings. The heat pump sources and sinks identified during the scoping assessments are listed in ***Table 1***. Although there are a variety of sources and sinks, various commonalities should be noted, including air-source heat sources and process heating water sinks.

Table 1: Identified Heat Pump Sources & Sinks

Segment	Heat Sources	Heat Sinks
Pulp & Paper	Mill Effluent Water	Process Heating Water
Chemical	Air Source	Heating Process Cooling Water HVAC Heating Water Process Heating Water
Wood Products	Boiler Stack Exhaust Air-Source Kiln Outlet Air Green Veneer Dryer Exhaust	Hog Fuel Drying Kiln Inlet Air Log Conditioning Water
High Tech	Air Source Process Cooling Water	Process Heating Water HVAC Heating Water
Food Processing	Air-Source Refrigeration Compressor Discharge Air Compressor Cooling Air	Sanitation Water Boiler Make-Up Water Blancher, Defrost water, Oil Clean-in-place water

The key heat pump temperatures by segment are shown in ***Figure 1*** below. It is shown that all sink temperatures in the study are below 225 °F. The segments are ordered according to the order used in ***Figure 2*** (descending percent savings). Although low lift is a known driver for heat pump viability, this is only marginally true from the graph (High Tech disrupts this trend). Obviously, there are other factors at play which will be discussed later in the report. A complete list of the measures including heat source, heat sink, source temperature, sink temperature, lift, COP, and operating hours can be found in ***Table 5*** in the Appendix.

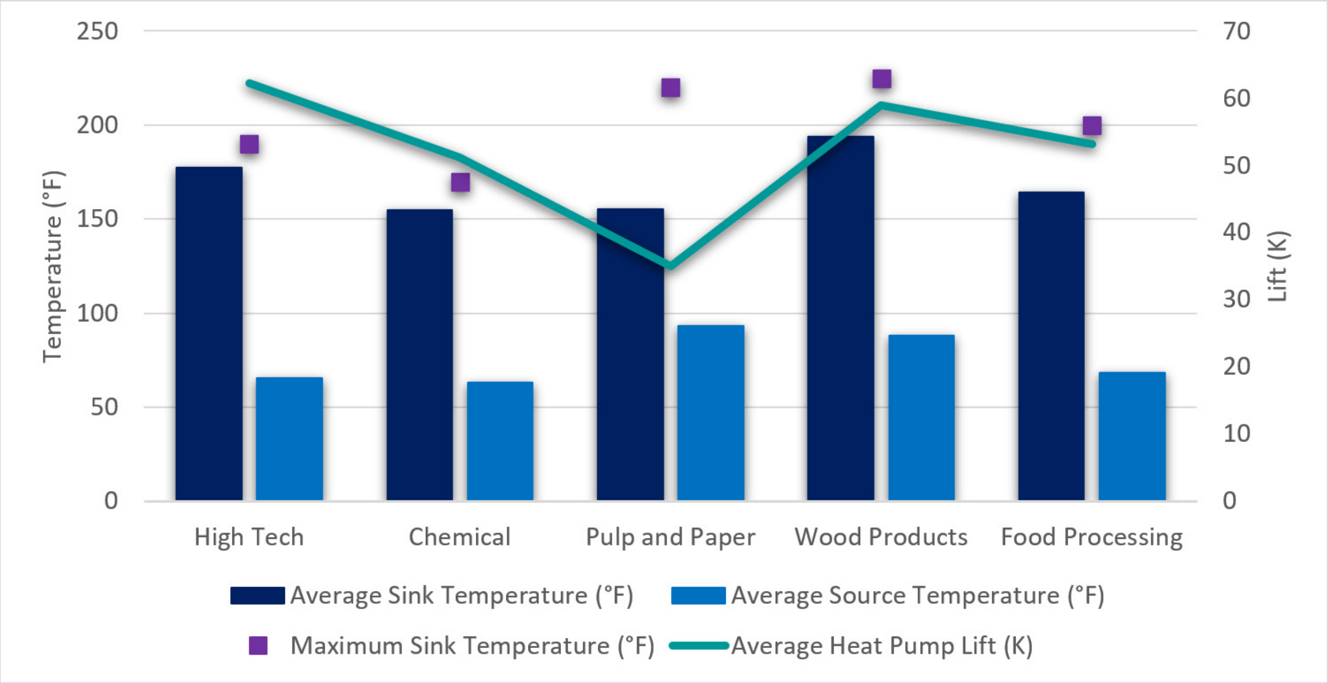

Figure 1. Heat Pump Operating Temperatures by Segment

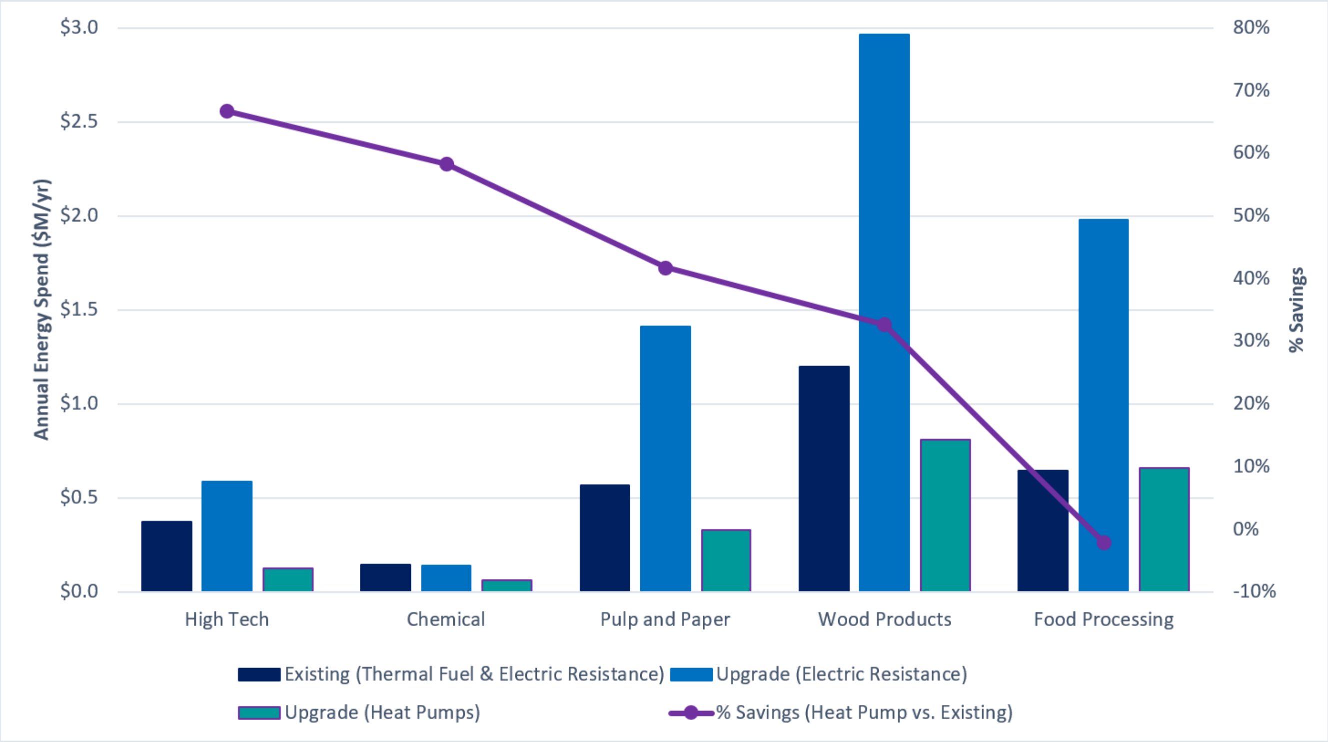

Figure 2. Annual Energy Spend for Package of Identified Measures

3.2 Heat Pump Economics

To assess economic feasibility, the study compared annual costs for each industry segment under three scenarios: the existing setup (using a mix of thermal fuel and electric resistance equipment), an upgrade to electric resistance equipment, and an upgrade to heat pumps. Notably in Figure 2, upgrading to less-efficient electric resistance equipment generally results in a significant increase in annual energy costs, while upgrading to heat pumps typically reduces annual energy expenses. High Tech and Chemical were the segments with the highest percent savings when comparing heat pumps to the existing setup. Pulp and Paper and Wood Products savings were still above 30%; however, the Food Processing savings were below 0%.

Note that only one pulp and paper site is included in Figure 2 due to energy spend being orders of magnitude larger than the others. Economics for this site (Pulp and Paper 1) are presented in ***Table 2***. Table 2 outlines the economic analysis of the heat pump measures averaged by site. It should be noted again that the information presented in this table is based on scoping-level calculations and cost estimates; therefore, it is subject to change with further investigation and analysis. The economics for all measures are included in ***Table 6*** in the Appendix.

Table 2 below presents the annual net cost savings from heat pump installations, calculated by comparing the total energy cost to serve the load, before and after the installation of a heat pump. As mentioned in Section 2, the IHP costs were based on Table 4 in the Appendix. An average of the “Economic” and “Technical” scenarios was used for the MVC (mechanical vapor compression), closed-cycle heat pump type. This value ($\$600/Q_{sink}$) was multiplied by the heat rate required by the sink (Q_{sink}) for each heat pump to calculate the total cost which includes equipment and installation. This is an average scoping-level estimate, and it should be noted that actual heat pump cost may vary. For HPWH installations, a cost estimation aligned with commercially available tank HPWHs was applied, using $50 per gallon of water used per day, based on estimates used by BPA in other energy efficiency programs.

Table 2. Heat Pump Economics by Site

Site	Spark Gap (Electric Cost / Existing Fuel Cost)	Total Estimated Annual Net Cost Savings	Total Estimated Heat Pump Cost	Total Estimated BPA Incentive	Total Estimated Payback (yrs) Before BPA Incentive	Total Estimated Payback (yrs) After BPA Incentive
Pulp and Paper 1	4.5	($1,980,000)	$27,080,000	$4,739,000	--	**--**
Pulp and Paper 2	2.5	$226,000	$3,570,000	$1,120,000	16	**11**
Chemical 1	1.1	$37,000	$86,000	$15,400	2.3	**1.9**
Chemical 2	n/a (electric baseline)	$46,000	$108,000	$75,600	2.3	**0.7**
Food Processing 1	3.2	$37,000	$1,658,000	$214,000	45	**39**
Food Processing 2	3.8	($17,500)	$2,333,500	$703,500	--	**--**
Wood Products 1	4.3	$130,000	$5,410,000	$975,000	42	**34**
Wood Products 2	n/a (electric baseline)	$292,000	$193,000	$135,100	0.7	**0.2**
High Tech 1	2.0	$228,000	$860,000	$147,000	3.8	**3.1**
High Tech 2	1.5	$20,000	$100,000	$31,500	5.0	**3.4**

BPA incentives in Table 2 were estimated based on projected electric savings achieved by switching to a heat pump, as compared to a less efficient electric resistance system baseline. The incentives were calculated at $0.33/kWh saved, up to a maximum of 70% of the total project cost. The baseline against which savings were measured varied; in some cases, the existing process already had an electric resistance baseline, while in other cases (biomass or natural gas boilers), a current practice, less efficient electric resistance baseline was created.

The findings from the scoping assessments revealed that, generally, transitioning to heat pumps from the electric resistance baselines had very favorable payback periods (less than 1 year) along with significant incentives. These incentives were included in the simple payback calculation in Table 2 for the overall project analysis (from existing fuel source to heat pump installation). While utilities may be interested in the savings relative to a current practice baseline, where necessary, the primary concern for industrial end-users is the financial viability of shifting from their existing equipment configurations to a heat pump system.

It is clear from Table 2 that the chemical and high-tech segments had more economically appealing heat pump projects. The reasons will be discussed in further detail in Section 4, but from a high level, this is related to more existing electric resistance equipment, lower sink temperatures, better suitability for air-source heat pumps, and lower spark gaps. It is also important to highlight the role utility incentives may play in improving the economics of these projects.

It is important to note that there is a state of Washington Cap-and-Invest Program will require sites emitting over 25,000 MT CO_2e per year to purchase allowances for their emissions. Currently, only the pulp and paper sites are affected by this requirement. However, to understand how future emissions pricing might affect heat pump economics in all states, a price of $50 per MT CO_2e reduced was applied to the viable site measure bundles above (all except Pulp and Paper 1 and Food Processing 2). The total simple payback was reduced from 5.5 years to 4.1 years (26%) due to these emissions savings. The price of emissions is based on recent auction prices,[a] however, it is market-driven, and thus, subject to change. This WA state program is separate from BPA and is only included to give customers a more comprehensive and realistic economic picture for heat pump upgrades.

3.3 Heat Pump GHG Emissions

The GHG emissions impacts for each segment are summarized in ***Figure 3*** by showing the percent reduction in metric tons of carbon dioxide equivalent (MT CO_2e) for the loads converted to heat pumps. It is clear from this chart that converting from a thermal fuel to a heat pump results in significant GHG savings. The electric resistance to heat pump upgrades (blue bars) may be meaningful from an energy savings perspective, but they are less significant from a GHG savings perspective when compared to thermal fuel upgrades.

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[a] The most recent carbon emissions offset information is available at https://ecology.wa.gov/air-climate/climate-commitment-act/cap-and-invest/auctions-and-market

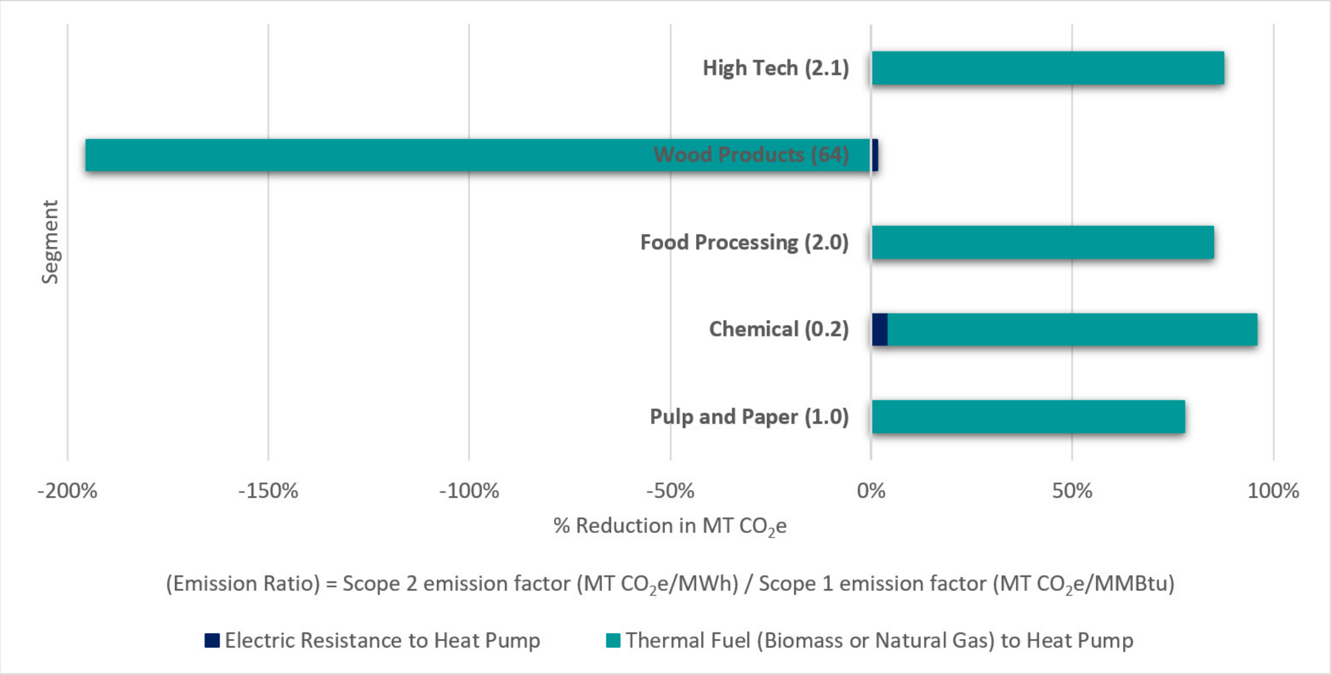

Figure 3. Heat Pump GHG Emissions Impacy by Segment

The values shown in parentheses are the emission ratios for each site. This is the ratio of the Scope 2 emission factor (emission rate related to purchased electricity) to the Scope 1 emission factor (emission rate related to the combustion of natural gas or biomass). A lower value indicates a better GHG savings opportunity for the heat pump upgrade. The wood products segment measures result in a net GHG increase for two reasons. One is that reducing biomass boiler emissions is less beneficial from a GHG perspective due to their CO_2 neutrality, as mentioned in Section 1.2. The other is that one of the wood products sites has a high electricity emission factor, so adding electricity use with a heat pump will result in higher emissions. It should be noted that one of the pulp and paper sites also has a biomass boiler, but since both pulp and paper sites also have low electricity emission factors, there was a net GHG reduction. The total GHG emissions savings for each heat pump measure are based on the calculations described in the Appendix.

4 Observations

4.1 Heat Pump Options

Based on the results of this study, it is apparent that all industrial sites have options when considering heat pumps. Below are key considerations when making these decisions:

4.1.1 Air-Source Heat Pumps

Functionality: These heat pumps may be commercial-type tank HPWHs or IHPs, and they function by extracting heat from ambient air. This offers a simpler setup due to less required piping, fewer heat exchangers, and less ancillary equipment.

Cost and Efficiency: Generally, these heat pumps are more affordable and less complex, but typically they are less efficient with lower COPs. This is not always the case, as exemplified in FP4. They are more suitable for smaller heating needs such as HVAC, boiler make-up water, or small discrete hot water demands.

Application Across Segments: These heat pumps are suitable for various applications including DHW, process heating, and HVAC, across all the industrial segments. While the pulp and paper segment showed no opportunities, this can be attributed to the large-scale heating demands at these facilities and the need to focus efforts on quantifying IHP opportunities. There is undoubtedly domestic HPWH potential at these sites.

4.1.2 Electric Resistance Baselines

Current Use and Replacement: The use of electric resistance heat to heat large volumes of process or cleaning water (C1-C3, FP1, and HT1 in Table 5 in the Appendix) was identified in several locations. It makes economic sense to replace these high-usage electric resistance loads with heat pumps, which are at least twice as efficient (COP > 2), resulting in very quick payback periods.

4.1.3 Custom Heat Pumps

Complexity & Scale: These industrial heat pumps are designed for larger-scale operations, capable of moving substantial heat quantities, often utilizing water-source technology and glycol pumping loops. These glycol pumping loops transfer heat on either side of the heat pump. Rather than heating a reservoir of water, these are integrated into two continuous process streams (source and sink). See Figure 6 in the Appendix for an example custom heat pump.

Economic Viability: While some custom heat pumps show positive economic returns, others do not. However, they offer considerable energy and potential GHG savings, making them worth considering for long-term planning, especially for companies with GHG reduction targets. Positive results were found in PP1, HT2, and HT3; however, in other cases (WP4, WP5, FP4, and FP5) the economics were poor. These projects are not insignificant when it comes to energy savings (and potentially GHG savings). Companies should consider these projects in the longer term, potentially after implementing more economically attractive air-source heat pump projects. Companies with GHG emissions targets may have heightened interest in pursuing these projects sooner. IHP and electrification projects may also be valued as a hedge against future energy prices, carbon pricing or other risk mitigation benefits.

4.1.4 Heat Recovery

Often, direct heat recovery presents a more cost-effective solution than heat pumps for reducing energy expenses. This method capitalizes on natural heat flow using heat exchangers when the source temperature is greater than the sink temperature, eliminating the need

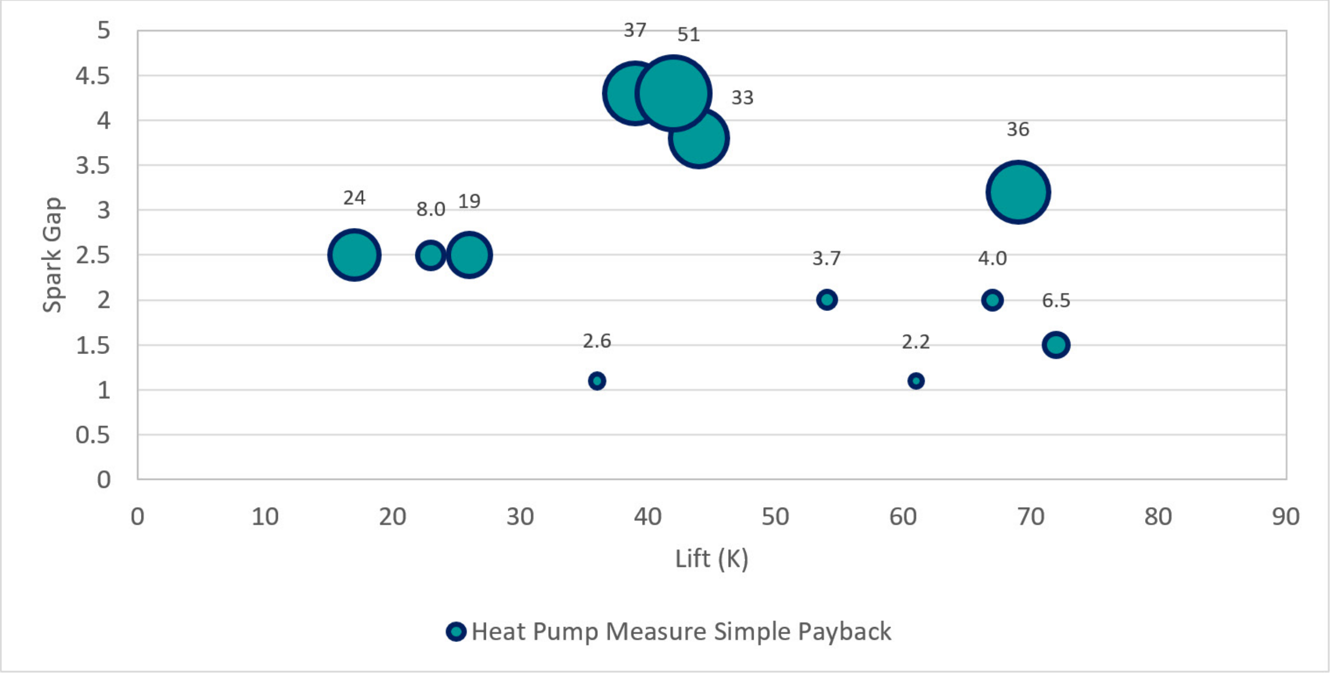

Figure 4. Economic Viability by Spark Gap and Lift

for a compressor and potentially satisfying the entire heating load. Even when the source temperature is lower than the sink temperature, implementing heat recovery can reduce the fuel consumption of the equipment heating the sink load by pre-heating the working fluid. An initial assessment of heat recovery opportunities was conducted across all sites.

Sites with natural gas or biomass-fired equipment have a significant source of energy in the exhaust stacks. Among the ten evaluated sites, only two of the sites - a wood products site and a food processing site - had stack economizers to recover heat from exhaust gases. The food processing site's economizer was offline as the boiler was currently not functional. Overall, food processing facilities have significant heat recovery opportunities because of the many pieces of direct gas-fired equipment (like steam boilers, ovens, dryers, fryers, roasters, etc.) that operate with high exhaust temperatures.

The wood products sites primarily had heat recovery potential from steam boiler stacks and kiln exhaust streams. One of the wood products sites already had heat recovery on the kiln, but it could further reduce energy costs by integrating a heat pump to capture latent heat in the air. That same site had a boiler stack economizer pre-heating boiler feedwater; however, significant heat remains in the exhaust air exiting the economizer to potentially be used as a heat pump heat source. This provides another key observation – heat recovery and heat pumps are not mutually exclusive; there is often enough heat to serve both systems.

4.2 Additional Key Observations

4.2.1 Spark Gap

The feasibility of heat pump projects is influenced by several key factors, including the temperature difference between heat sources and sinks (heat pump lift), the operational synchronization of heat sources and sinks, the heat pump operating hours, the spark gap, and the overall project cost. The lift also affects the heat pump Coefficient of Performance (COP). These factors, along with operating hours and spark gap (the ratio of electricity cost to existing fuel cost, expressed in equivalent units) are included in Tables 5 and 6. The spark gap directly influences the economic return of heat pump projects, with projects showing quicker paybacks (less than 15 years) when the spark gap is below 2.5 (see smaller circles in Figure 4). This holds true even when other factors may be generally unfavorable (e.g. operating hours below 4,000 or COP less than than 3). This importance of spark gap over other key factors is also demonstrated in Figure 4 as low payback projects are shown for a wide range of temperature lifts (and by extension, COPs). While the data from this study is not extensive enough to draw definitive conclusions, the findings suggest that the spark gap should be considered one of the top factors for assessing the viability of heat pump projects.

4.2.2 Biomass Boiler Baselines

In this study, all four sites within the wood products and pulp and paper segments use biomass boilers for steam generation, primarily consisting of hog fuel – a mix of coarse bark chips and wood fiber - and lumber/plywood trim. The economic outlook for heat pump projects at these sites is generally unfavorable due to the low cost of biomass fuel compared to electricity, when measured on an equivalent energy output basis. Biomass is either sourced on-site at a minimal cost or sourced externally at a lower cost than electricity. One pulp and paper site, however, did have economically viable heat pump projects (PP1-PP3). This was attributed to the use of a natural gas boiler, rather than a biomass boiler, to serve the loads evaluated for heat pumps.

GHG Emissions Insights: From a GHG emissions perspective, it was determined that biomass boiler baselines provide less potential for GHG reduction than natural gas boiler baselines. This is because the carbon dioxide (CO_2) embodied in biomass is considered biogenic (it was biologically sequestered during photosynthesis). When the biomass is combusted, this CO_2 is released back into the atmosphere, in a net-zero process. Therefore, only emissions of methane (CH_4) and nitrous oxide (NO_2) can be considered as new emissions. Although these gases have a much higher global warming potential (GWP) than CO_2, they represent a small fraction of CO_2-equivalent emissions, so the overall emissions impact of these biomass-baseline heat pump projects is greatly reduced. Despite the complexity surrounding the accounting of biogenic CO_2, this method is widely accepted in the industry and aligns with GHG accounting standards, such as the Greenhouse Gas Protocol.[b]

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[b] World Resources Institute. The Greenhouse Gas Protocol, Page 63. Available at: https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf

A wood products customer in this study confirmed this approach to accounting for biomass emissions. The heat pump projects at this site would result in increased overall GHG emissions, due to additional electricity purchased from the grid. Conversely, the projects at the pulp and paper site using a biomass boiler would result in decreased overall emissions. As mentioned in Section 3, this difference can be attributed to the difference in electric utility (Scope 2) emission factors. Heat pumps at the wood products site would use electricity from a utility whose generation source has a higher emission intensity. In either case, including biogenic emissions in the calculation would dramatically change the emissions savings outcomes. Specifically, the projects at the wood products site would deliver positive GHG savings, instead of negative, and the pulp and paper site projects would deliver even higher GHG savings.

This nuanced examination reveals the significant role of energy source economics and emission intensity in determining the viability and environmental impact of heat pump projects within these segments, as detailed in the accompanying GHG savings comparison in Table 4.

4.2.3 Corporate GHG Goals

The study surveyed all participating sites regarding their corporate greenhouse gas (GHG) reduction objectives. The responses revealed varying levels of commitment to sustainability and specific environmental targets:

- **Defined GHG Goals:** Four sites had specific, measurable, time bound GHG reduction goals (i.e. 30% GHG reduction by 2030).

- **Energy Intensity Goal:** Two sites had specific, measurable, time bound energy or energy intensity goals at the corporate level.

- **Sustainability Commitment:** Another site expressed a general commitment to sustainability.

- **No Corporate Goals:** The remaining three sites did not have corporate goals.

Additionally, when asked about their company's flexibility regarding payback periods for energy efficiency investments:

- **Flexible Payback Periods:** Two sites confirmed their companies are willing to accept longer payback periods for projects that contribute to energy efficiency.

- **Carbon Reduction Consideration:** One site, while not flexible on payback periods, noted that carbon reduction impacts are a factor in funding decisions, highlighting the growing importance of environmental considerations in corporate financial planning. No organizations currently place a value on carbon as a standard practice in assessing project economics.

Overall, knowledge of IHP technology was low across the sites. Even among those with explicit corporate GHG reduction goals, there was a lack of familiarity with industrial heat pump technologies. And they had not considered potential applications. This gap suggests an opportunity for increased awareness and education on the benefits and applications of heat pump technology in industrial settings.

GHG Potential and Project Impact: The GHG goals, along with the estimated GHG savings for the package of identified heat pump projects, were assessed for each site, with the findings highlighted in Table 3. The analysis indicates that sites converting natural gas loads to electric heating solutions, such as heat pumps, will see the largest GHG reductions. Table 3 also showcases the sizeable impact on percent non-biogenic GHG reduction for four sites with natural gas (Pulp and Paper 2 and High Tech 1), biomass (Pulp and Paper 2), and electric resistance (Wood Products 2) baselines.

This portion of the study underscores the importance of aligning energy efficiency projects, including the adoption of heat pump technology, with corporate environmental goals. It highlights a broader trend toward sustainability in the industrial sector, while also pointing out the need for better awareness and understanding of the technologies available to achieve these goals. The contrast between the stated corporate commitments to GHG reduction and the current level of knowledge and implementation of IHP technologies suggests an area ripe for development and focus, both for individual companies and the broader industry.

Table 3. GHG Reduction Goals & Savings Summary by Site

Site #	Corporate GHG Reduction Goal?	Specific Corporate Goal	Heat Pump Projects in Package	Estimated Package Annual GHG Savings (MT CO$_2$e/yr)	Site % Non-Biogenic GHG Reduction[1]
Pulp and Paper 1	Yes	Corporate GHG reduction of 27.5% by 2030	1	-17,200	-8%
Pulp and Paper 2	No	General commitment to sustainability	3	-6,130	-14%
Chemical 1	No	Corporate *energy* use reduction of 30% by 2030	2	-264	n/a
Chemical 2	No		3	-12	n/a
Food Processing 1	No	Corporate *energy* intensity reduction of 10% by 2030	3	-3,040	n/a
Food Processing 2	Yes	Corporate GHG intensity reduction of 20% by 2030	4	-3,602	n/a
Wood Products 1	Yes	Corporate GHG reduction of 30% by 2030	3	1,630	n/a
Wood Products 2	No		2	-120	-20%
High Tech 1	Yes	Global carbon neutrality by 2050	2	-2,200	-19%
High Tech 2	No		2	-148	n/a

[1] Site % Non-Biogenic GHG Reduction based on 2022 reported emissions reported through the Washington Department of Ecology (Available at: https://ecology.wa.gov/Air-Climate/Reducing-Greenhouse-Gas-Emissions/Tracking-greenhouse-gases/Mandatory-greenhouse-gas-reports). Sites with no value

5 Conclusions & Recommendations

5.1 Conclusions

The study yielded several key findings regarding the feasibility and impact of heat pump projects across various industry segments:

1. Industry Segment Viability

- Heat pump projects are viable in every industry segment, with air-source heat pumps being a universally applicable option, albeit on a smaller scale.
- The high tech and chemical segments emerge as particularly suitable for heat pump integration due to both low temperature processing water heating loads and existing electric resistance heating loads.
- While food processing is a viable industry for heat pumps, opportunities for more cost-effective direct heat recovery should be evaluated prior to heat pump implementation.
- The economic viability and GHG reduction potential in the pulp and paper and wood products segments may be more limited due to biomass fuel baselines.

2. Project Viability Considerations

- Projects that currently rely on electric resistance loads present immediate opportunities for heat pump applications.
- Although direct heat recovery is a priority consideration, this does not preclude the potential for heat pumps for further efficiency gains.
- The spark gap, comparing electricity costs to existing fuel costs, should always be considered and is likely a more important metric than other heat pump metrics (i.e. lift, operating hours).

3. Role of Utility Incentives

- Utility incentives based on comparison to a current practice, less-efficient electric resistance alternative are crucial to enhance the economic viability of heat pump installations. This will help offset the high initial capital costs associated with these technologies.

4. Future of Heat Pumps

- Heat pumps will play an increasingly important role as corporations and government entities place more emphasis on GHG emissions reduction.

- Legislative actions, such as the emissions pricing seen in states like Washington, further strengthen the case for adopting heat pump technologies. Focus should be placed on replacing natural gas loads with heat pumps as this will provide the most sizeable GHG reductions.

This comprehensive analysis underscores the potential of heat pump technology to contribute significantly to energy efficiency and GHG emissions reduction goals across a broad spectrum of industrial applications. The findings advocate for a strategic approach to selecting and implementing heat pump solutions, considering the unique characteristics and needs of each industry segment.

5.2 Recommendations For Further Research

As the industrial heat pump market evolves, further research is essential to address outstanding questions and maximize the technology's potential. Below are the key recommendations for further research to assist in answering these questions:

1. **Custom Heat Pump Measures:** Perform an in-depth study of at least one custom heat pump measure in each industry segment. It will be valuable to gather precise data on vendor pricing and process integration costs and perform a more in-depth energy and GHG savings analysis. This effort should focus on sites with GHG goals, favorable spark gaps, and electric resistance baselines.

2. **All-Electric Baseline Feasibility**: Explore whether an all-electric baseline is realistic from an economic and practical standpoint. Despite the anticipated increase in costs, as shown in Figure 1, motivations such as GHG reduction objectives, the push for electrification, and regulatory pressures could still justify such a move. One example includes a site that, prior to this heat pump study, was seriously considering the installation of electric boilers driven by the cost of purchased steam and the price of emissions in WA. Assessing the feasibility of upgrading the electrical infrastructure required to serve new all-electric equipment will inform utilities about the appropriateness of offering incentives for heat pumps as an alternative to less-efficient electric resistance equipment

3. **Regional Heat Pump Potential:** Perform a comprehensive study to understand the long-term prospects for heat pump adoption in the Pacific Northwest, beyond individual industry segments. This broader analysis is necessary to evaluate macro-level potential and explore important questions such as: the impact of heat pumps on both electric load in the region and electric savings potential; the future of carbon pricing in the region and the expected future costs of heat pumps. Such research will provide valuable insights into the strategic positioning of heat pumps within the region's energy transition and climate goals.

These recommended research directions aim to fill knowledge gaps and support the strategic deployment of heat pump technologies across various industrial sectors. By addressing these questions, stakeholders can better understand the role of heat pumps in achieving energy efficiency improvements, cost savings, and GHG emission reductions.

APPENDIX

Tables and Figures

Table 4. IHP Cost Table Used in Scoping Analysis [2]

Table B1. Capital cost estimates for the six IHP types for economic and technical scenarios.

IHP type	Economic scenario capital cost, \$U.S./Q_{sink} (kW)	Technical scenario capital cost, \$U.S./Q_{sink} (kW)
MVC, closed cycle	400	800
MVR, semi-open cycle	325	650
MVR, open cycle	250	500
TVR, open cycle	150	NA
HA Type 1, closed cycle	1,000	1,500
HA Type 2, closed	1,250	1,875

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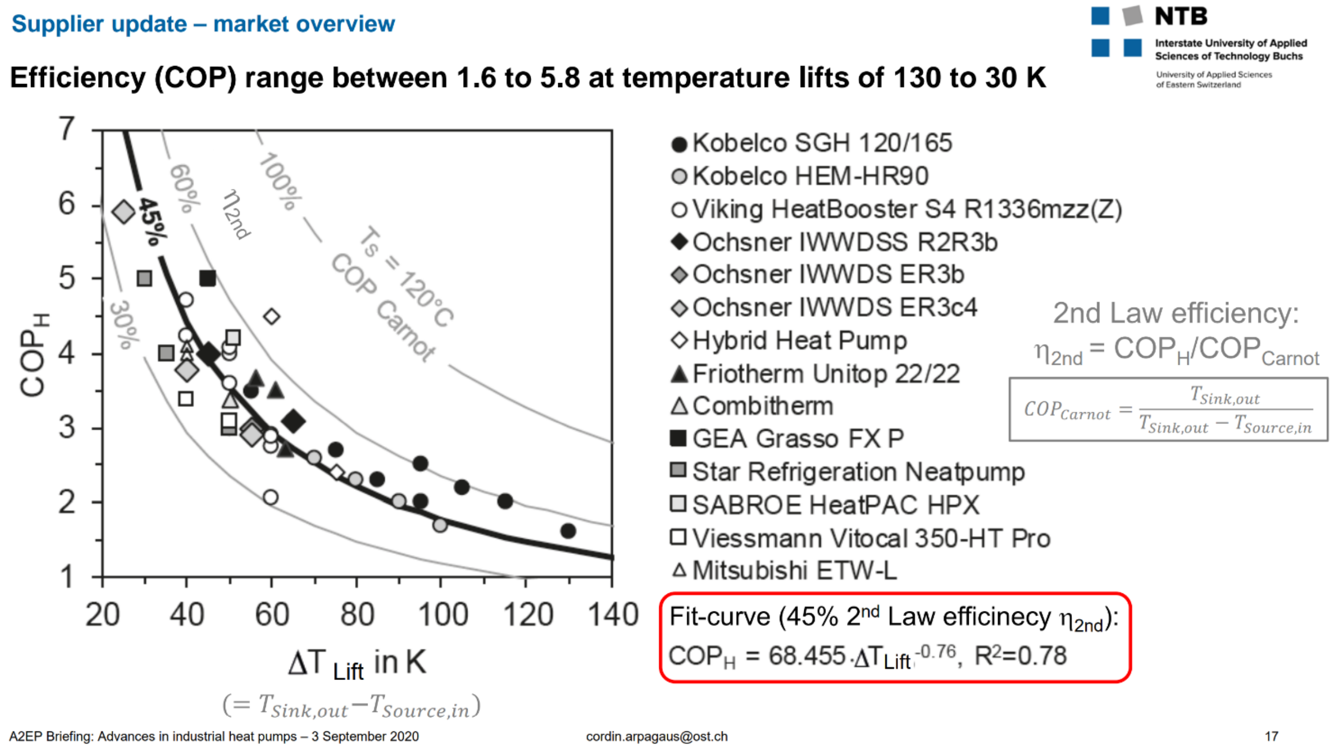
[2] [ACEEE, March 2022, 'Industrial Heat Pumps: Electrifying Industry's Process Heat Supply' Report, Appendix B: IHP Economics and Capital Cost Parameters, page 66 of 73]. Average of MVC scenario costs was used in analysis (\$600/Q_{sink}).



Supplier update – market overview

NTB
Interstate University of Applied Sciences of Technology Buchs
University of Applied Sciences of Eastern Switzerland

Efficiency (COP) range between 1.6 to 5.8 at temperature lifts of 130 to 30 K

2nd Law efficiency:

$$\eta_{2nd} = COP_H/COP_{Carnot}$$

$$COP_{Carnot} = \frac{T_{Sink,out}}{T_{Sink,out} - T_{Source,in}}$$

Fit-curve (45% 2^{nd} Law efficinecy η_{2nd}):

$COP_H = 68.455 \cdot \Delta T_{Lift}^{-0.76}$, $R^2=0.78$

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Figure 5. Lift vs. COP Graph & Curve Fit Used in Scoping Analysis [3]

[3] [Dr. Cordin Arpagaus. September 2020. "Industrial Heat Pumps – Supplier Update, suitable refrigerants and application examples in food & steam generation"]

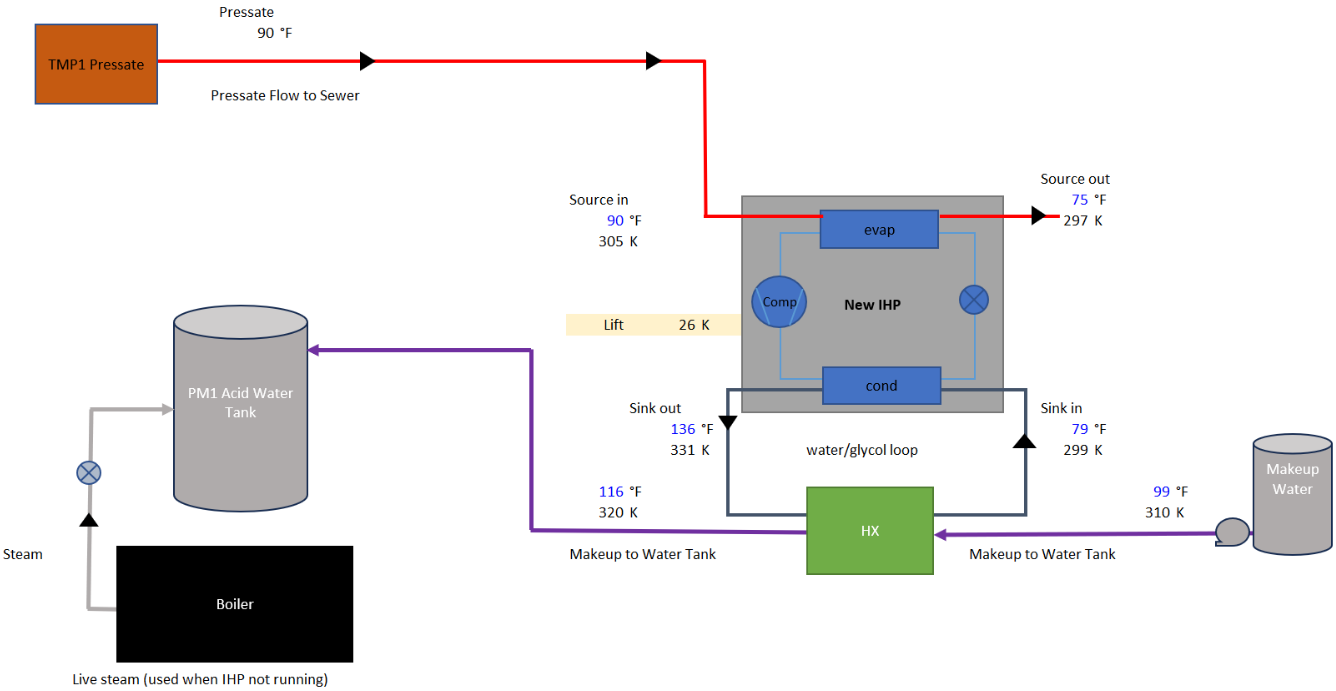

Figure 6. Example Custom IHP Conceptual Design

Table 5. Heat Pump Temperature & COP by Measure

Heat Pump Measure	Measure #	Heat Source	Heat Sink	Source Temp (°F)	Sink Temp (°F)	Heat Pump Lift (K)	Estimated Heat Pump COP	Hours
Pulp and Paper 1	PP1	Mill effluent water	Process heating water	90	131	23	5.8	3,890
Pulp and Paper 2	PP2	Mill effluent water	Process heating water	90	136	26	5.8	5,698
Pulp and Paper 3	PP3	Mill effluent water	Process heating water	105	135	17	5.8	7,405
Pulp and Paper 4	PP4	Mill effluent water	Process heating water	87	220	74	2.6	8,322
Chemical 1	C1	Air-source	Heated process cooling water	65	160	53	2.5	8,760
Chemical 2	C2	Air-source	Heated process cooling water	65	160	53	2.5	4,992
Chemical 3	C3	Air-source	Heated process cooling water	65	160	53	2.5	4,992
Chemical 4	C4	Air-source	HVAC heating water	60	170	61	2.0	8,760
Chemical 5	C5	Air-source	Process heating water	60	125	36	2.5	8,760
Food Processing 1	FP1	Air-source	Sanitation water	60	180	67	2.0	624
Food Processing 2	FP2	Air-source	Domestic hot water	60	120	33	3.0	5,500
Food Processing 3	FP3	Air-source	Domestic hot water	60	120	33	3.0	8,343
Food Processing 4	FP4	Air-source	Boiler make-up water	70	149	44	4.5	8,760
Food Processing 5	FP5	Refrigeration compressor discharge	Blancher, tunnel defrost water, oil	75	200	69	2.7	8,343
Food Processing 6	FP6	Air compressor cooling air	Hot water hoses	90	180	50	3.5	1,599
Food Processing 7	FP7	Refrigeration compressor discharge	Blanchers, clean-in-place water	63	200	76	2.5	5,500
Wood Products 1	WP1	Boiler stack exhaust	Hog fuel drying (new)	80	225	81	2.4	8,400
Wood Products 2	WP2	Air-source	Surface water runoff evaporation (new)	55	225	94	2.2	8,400
Wood Products 3	WP3	Air-source	Domestic hot water	50	120	39	3.0	5,400
Wood Products 4	WP4	Kiln outlet air	Kiln inlet air	155	225	39	4.2	5,996
Wood Products 5	WP5	Green veneer dryer exhaust	Log conditioning water	100	175	42	4.0	5,400
High Tech 1	HT1	Air-source	Process heating water	60	160	56	2.5	5,423
High Tech 2	HT2	Process cooling water	HVAC heating water	82	180	54	3.3	8,760
High Tech 3	HT3	Process cooling water	Process heating water	60	180	67	2.6	6,320
High Tech 4	HT4	Air-source	Process heating water	60	190	72	2.0	5,423

Table 6: Heat Pump Economics by Measure

Measure #	Existing Fuel type	Spark Gap (Electric Cost / Existing Fuel Cost)	Estimated Annual Net Cost Savings	Estimated Heat Pump Cost	Estimated BPA Incentive	Estimated Payback (yrs) Before BPA Incentive	Estimated Payback (yrs) After BPA Incentive	Estimated Payback (yrs) Including WA Annual Cost of Emissions
PP1	Purchased Steam (Natural Gas)	2.5	$98,000	$830,000	$147,000	8.0	7.0	4.6
PP2	Purchased Steam (Natural Gas)	2.5	$72,000	$1,370,000	$455,000	19	13	7.5
PP3	Purchased Steam (Natural Gas)	2.5	$56,000	$1,370,000	$518,000	24	15	7.5
PP4	Biomass (75%)/Natural Gas (25%)	4.5	($1,980,000)	$27,080,000	$4,739,000	--	--	--
C1	Electric Resistance	n/a	$22,000	$36,000	$25,200	1.5	0.5	n/a (below threshold)
C2	Electric Resistance	n/a	$12,000	$36,000	$25,200	2.6	0.9	
C3	Electric Resistance	n/a	$12,000	$36,000	$25,200	2.6	0.9	
C4	Natural Gas	1.1	$24,000	$52,000	$6,300	2.2	1.8	
C5	Natural Gas	1.1	$13,000	$34,000	$9,100	2.6	2.2	
FP1	Electric Resistance	n/a	$5,000	$61,500	$8,000	12	10	n/a (below threshold)
FP2	Electric Resistance	n/a	$500	$15,000	$6,000	30	18	
FP3	Electric Resistance	n/a	$2,000	$60,000	$20,000	30	20	
FP4	Natural Gas	3.8	$24,000	$800,000	$442,400	33	15	
FP5	Purchased Steam (Natural Gas)	3.2	$33,000	$1,202,000	$146,000	36	32	
FP6	Purchased Steam (Natural Gas)	3.2	$2,000	$396,000	$48,000	198	174	
FP7	Natural Gas	3.8	($47,000)	$1,457,000	$247,100	--	--	
WP1	Electric Resistance	n/a	$118,000	$74,000	$51,800	0.6	0.2	n/a (below threshold)
WP2	Electric Resistance	n/a	$174,000	$119,000	$83,300	0.7	0.2	
WP3	Electric Resistance	n/a	$3,000	$50,000	$30,000	31	22	n/a (non-WA)
WP4	Biomass (97%)/Natural Gas (3%)	4.3	$82,000	$3,050,000	$539,000	37	31	n/a (non-WA)
WP5	Biomass (97%)/Natural Gas (3%)	4.3	$45,000	$2,310,000	$406,000	51	42	n/a (non-WA)
HT1	Electric Resistance	n/a	$9,000	$26,000	$18,200	3.0	0.9	n/a (non-WA)
HT2	Natural Gas	2.0	$165,000	$610,000	$105,000	3.7	3.1	n/a (below threshold)
HT3	Natural Gas	2.0	$63,000	$250,000	$42,000	4.0	3.3	
HT4	Natural Gas	1.5	$11,000	$74,000	$13,300	6.5	5.4	n/a (non-WA)

GHG Calculation References

1. Scope 1 (natural gas and biomass) emissions calculated based on published CO2, CH4, and NO2 emission factors. (The Climate Registry. *2023 Default Emission Factors*, Table 1.1, Table 1.7. Available at: https://theclimateregistry.org/wp-content/uploads/2023/06/2023-Default-Emission-Factors-Final-1.pdf)

2. Scope 2 (purchased electricity) emissions calculated based on BPA utility-specific emission factors (0.01-0.04 MT CO2e/MWh).

    i. Washington utilities: Washington Department of Commerce. May 2023. *Utility GHG Emissions Report 2020_1_11*. Available at https://www.commerce.wa.gov

    ii. Oregon utilities: State of Oregon Department of Environmental Quality. Updated Electricity Carbon Intensity Values for 2021. https://www.oregon.gov/deq/ghgp/Documents/cfpUpdated2021CIs.pdf

    iii. Utilities without published values: A Pacific Northwest wholesale emission factor of 0.2 MT CO2e/MWh was used. (Roberts, Anika. May 2020. *Update on Carbon Emissions from the Power Sector*.) Available at: https://www.nwcouncil.org/news/update-annual-greenhouse-emissions-power-sector/

3. Scope 2 (purchased steam and heat) emissions calculated based on EPA published GHG emission factor (0.066 MT CO2e/MMBtu). (EPA, “Emission Factors for Greenhouse Gas Inventories”, Table 7. Two sites purchase steam for their heating needs. One of the sites knew that this steam was generated from natural gas boilers, so the natural gas Scope 1 emission factor was applied. The other site did not know the fuel inputs to the steam boiler, so a purchased steam-specific Scope 2 emission factor was applied. Available at: [https://www.epa.gov/system/files/documents/2023-03/ghg_emission_factors_hub.pdf.](https://www.epa.gov/system/files/documents/2023-03/ghg_emission_factors_hub.pdf)